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(54) **REVERSIBLE AIR-WATER ABSORPTION HEAT PUMP**

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(57) **ABSTRACT**

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A cooling or heating device in an absorption heat pump of GAX type, including a generator, a GAX heat exchanger, an absorber, a condenser, an evaporator, a pump connected to the absorber and generator, and a first circuit for refrigerant solution circulating through the device and connecting together at least the generator, GAX heat exchanger, absorber, condenser, evaporator, and pump. A valve device modifies the first circuit to vary the manner in which the absorber, condenser, and evaporator are connected together. At least first and second heat exchanger units enable at least one phase of the circulating solution to be changed and to enable thermal energy to be exchanged against an external fluid, the first and second heat exchanger units each including at least two mutually separate sub-heat exchangers configured to function either as an evaporator or as an absorber and condenser, depending on an operating mode of the device.

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62/476, 484, 489, 494, 324.2

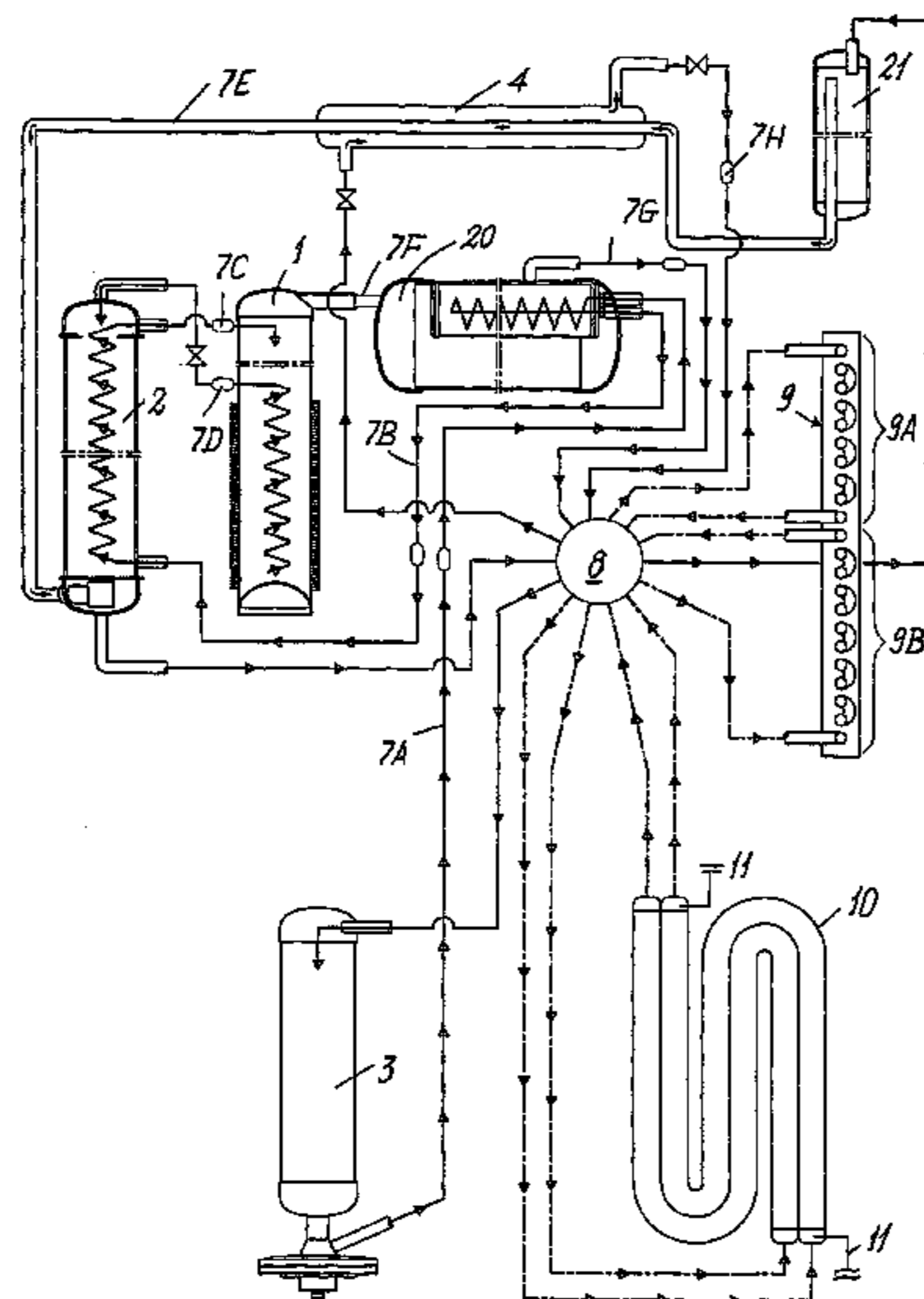
See application file for complete search history.

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**15 Claims, 4 Drawing Sheets**



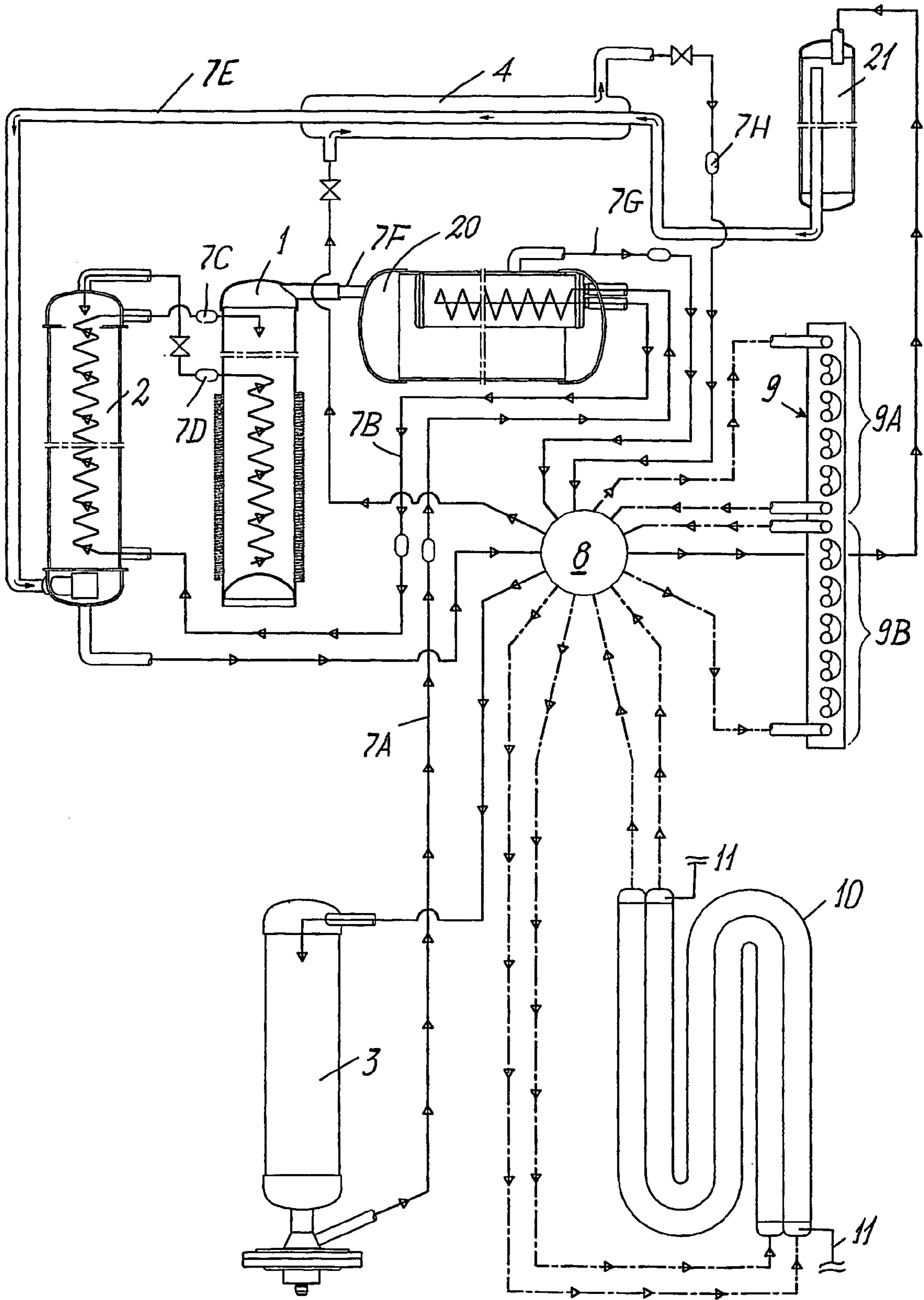


FIG. 1A

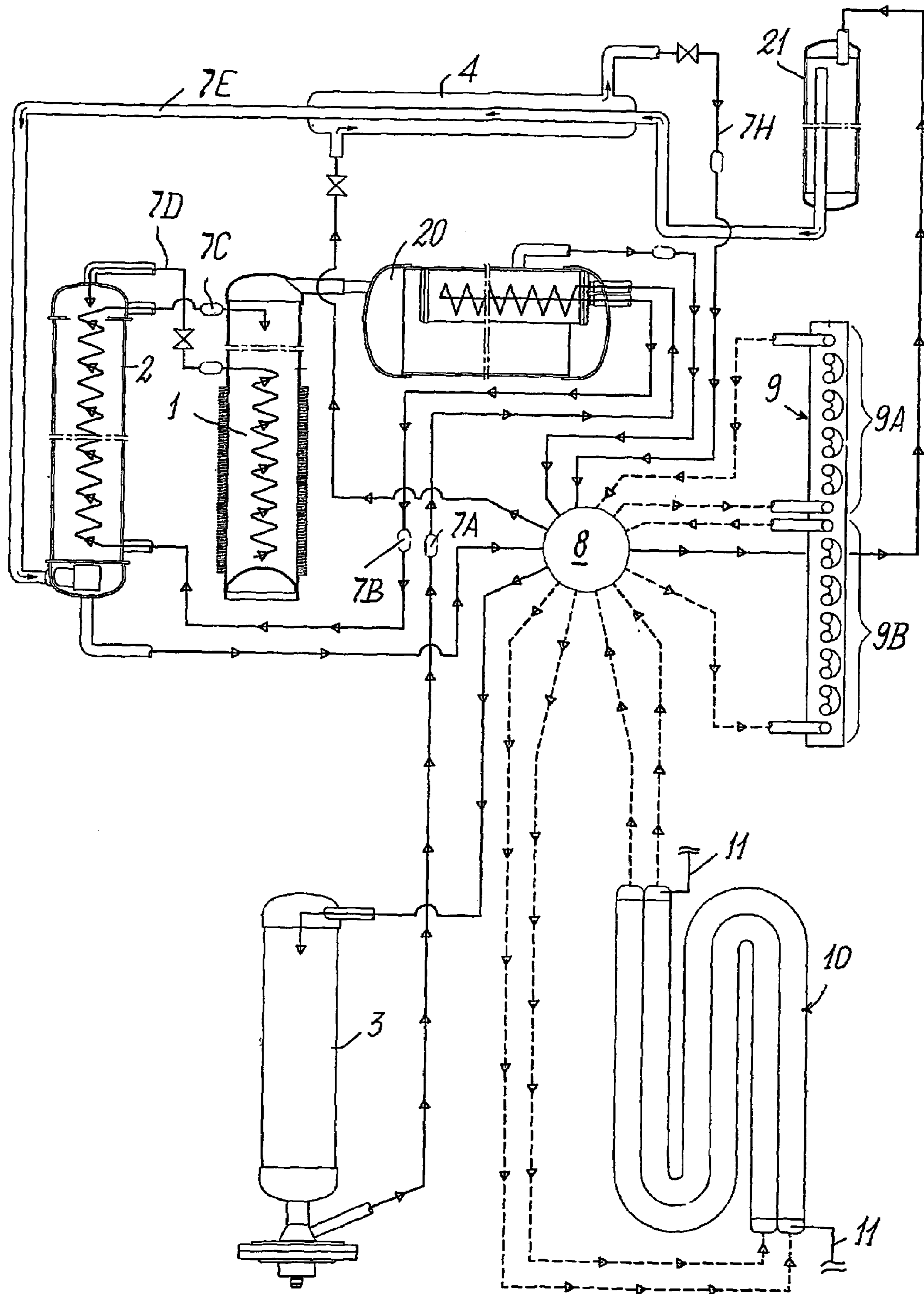


FIG. 1B



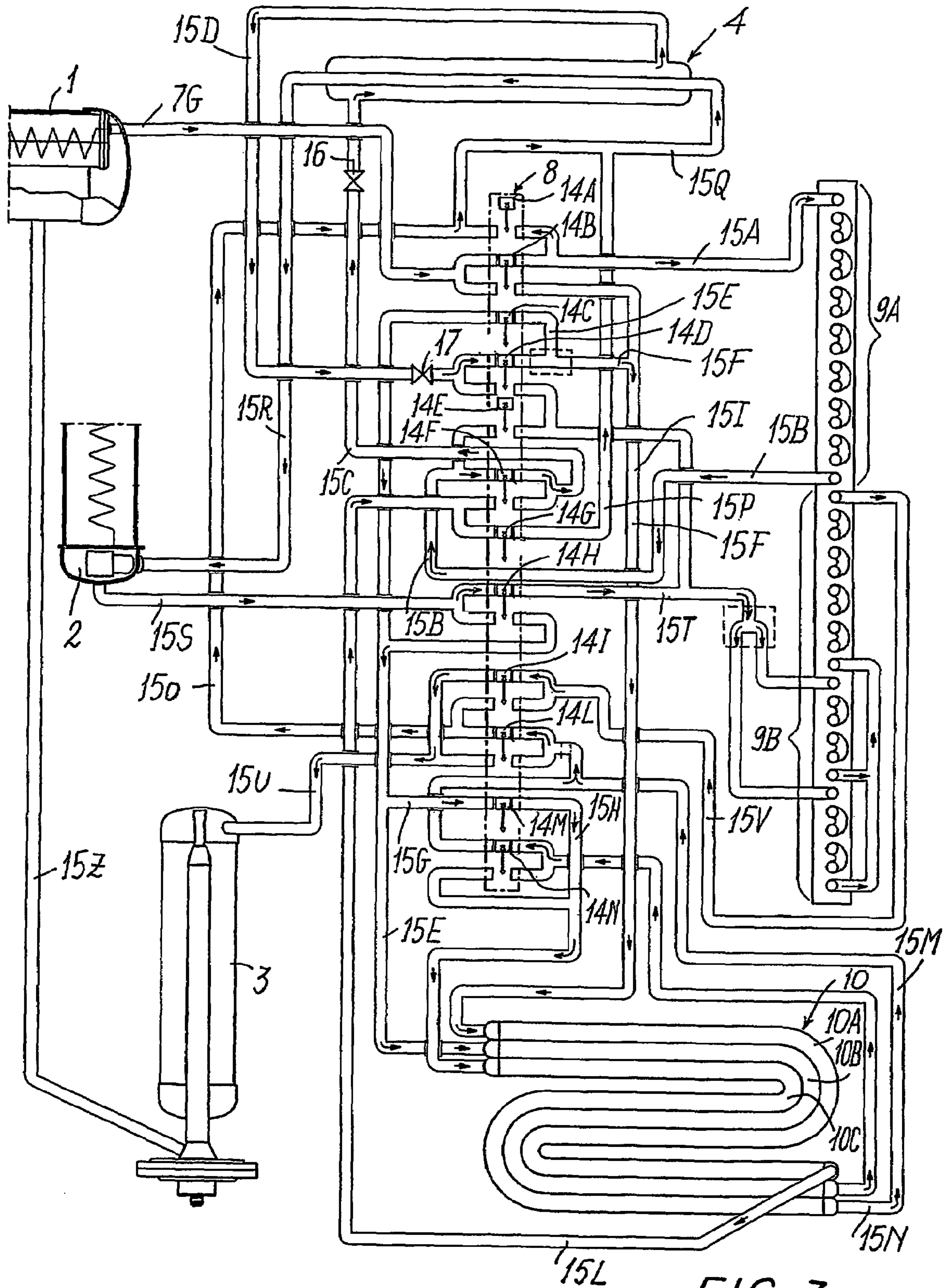


FIG. 3

## REVERSIBLE AIR-WATER ABSORPTION HEAT PUMP

The present invention relates to a cooling and/or heating device in an absorption heat pump of GAX type, in accordance with the pre-characterising part of the main claim.

Devices of the aforesaid type are described for example in U.S. Pat. No. 6,000,235, in U.S. Pat. No. 6,646,541 and in U.S. Pat. No. 4,719,767. The known devices comprise valve means for inverting the absorption cycle at the evaporator and condenser, so that those heat exchangers which during operation in heating mode act as the condenser and evaporator are arranged to act respectively as the evaporator and condenser during operation in cooling mode.

The devices of the aforesaid type comprise at least two distinct and separate hydraulic circuits for dispersing the heat generated in the absorber, and in the means which function as evaporator during operation in cooling mode and as condenser during operation in heating mode (see for example U.S. Pat. No. 4,646,541). The presence of these two distinct hydraulic circuits for dispersing the heat considerably complicates the control and design both of the device overall and of the plant to which this device is connected.

Moreover in known devices the circuit through which the refrigerant solution passes and which connects together the various components of the device requires relatively complicated and costly valve and control means to ensure reliable passage of the device from one operating mode to the other; for example difficulties can arise because of the possible accumulation of solution and/or refrigerant within those circuit sections which are not in use, leading to uncertainties in the solution and refrigerant level within the circuit, to cause operating instability and substantial variations in efficiency.

An object of the present invention is to provide an absorption cooling and/or heating device of GAX type which is more compact and of easier operation and handling than traditional devices.

A further object is to provide a device which enables the hydraulic exchange circuit for the thermal energy generated or provided within the absorber and in the evaporator/condenser to be simplified.

A further object is to provide a device which enables the valve and control means present in the circuit for passage of the refrigerant solution to be simplified.

These and further objects which will be apparent to an expert of the art are attained by a device in accordance with the characterising part of the accompanying claims.

The present invention will be better understood from the accompanying drawings which are provided by way of non-limiting example and in which:

FIGS. 1A, B are a schematic view of the device showing operation in heating mode and in cooling mode respectively;

FIGS. 2 and 3 are a simplified schematic view showing the connections of the various components of the device when operating in heating mode and in cooling mode respectively.

With reference to said figures, these show a usual generator 1, a heat exchanger 2 of GAX type, a usual pump 3, a usual subcooler-recuperator 4, a usual rectifier 20 for the vapour prior to its entry into the condenser and a usual vessel 21 for checking the refrigerant concentration.

The said components and the relative connection circuit indicated overall by 7A–H are of conventional type and will therefore not be described in detail hereinafter. The device also comprises sixteen/fourteen way valve means and two

heat exchange means 9 and 10 for changing a phase of the refrigerant solution circulating through the said means.

According to the invention, when the device operates in cooling mode (FIG. 3) the valve means 8 are arranged to modify the circuit which connects together the various components of the device such that the first heat exchange means 10 operates as an evaporator and the second 9 operates partly as a condenser and partly as an absorber; in contrast, when the device operates in heating mode the evaporator means are arranged to modify said circuit such that the first heat exchange means 10 operates partly as an evaporator and partly as an absorber, and the second 9 as an evaporator.

The heat exchange means 9 and 10 are of traditional type; preferably the heat exchange means 10 is of the fluid-liquid type and hence comprises a hydraulic circuit 11 (shown schematically in FIGS. 1A, 1B) to drive a liquid circulating through said circuit and passing through said heat exchanger. The hydraulic circuit will not be further described, being of traditional type. Preferably the heat exchanger 10 is of the type described in European application EP0911597, the description of which is to be considered as incorporated into the present text. The heat exchanger 10 comprises at least two tube bundles arranged to form two separate sub-heat exchangers 10A, B, C, presenting separate inlets and outlets. In one possible implementation of the invention the separate sub-heat exchangers 10A, B, C are three in number and are disposed side by side to form an “S”. It should be noted that for optimum operation of the heat exchanger 10, each of its parts 10A–C must comprise a tube bundle with tubes having a diameter between 8 mm and 16 mm. In this respect it has been verified experimentally that such heat exchangers enable the useful passage cross-sections for the fluids passing through them to be balanced in order to optimize the hydraulic characteristics (circuit pressure drops) and thermodynamic characteristics (heat and mass transfer and phase change) in both the modes in which the heat exchangers are required to operate. In known appliances in which the cycle inversion takes place only between evaporator and condenser the refrigerant flow rate is identical in both heat exchangers, and the phase change is in the opposite sense but with very similar thermodynamic characteristics; in contrast, in the present invention the circuit inversion also involves the absorber, which has fluid flow rates and thermodynamic characteristics completely different from the evaporator and condenser.

The heat exchange means 9 is of the fluid-air type and hence comprises usual finning (not shown) for transferring to the surrounding air the thermal energy developed within the heat exchanger tubes. The heat exchanger 9 preferably comprises within a single bank two separate sub-heat exchangers 9A, B presenting separate connections indicated by 12A, B and 13A, B, C acting, in the manner explained hereinafter, and at the required time, as inlets or outlets for the solution circulating through the device.

Advantageously the inlets 13A are split to optimize pressure drops and fluid balancing when operating in cooling mode.

It should be noted that the heat exchanger 9 is constructed as a single bank for size and constructional reasons, but could be constructed as two or more usual separate banks. In the same manner the heat exchanger 9 could also be of fluid-liquid type even though such a solution would have the complication of having to provide for each sub-heat exchanger a hydraulic circuit for circulating the liquid which

is to receive or give up the thermal energy developed or required during the phase changes which take place within said sub-heat exchangers.

From a functional schematic viewpoint the valve means **8** comprise twelve usual two or three-way valve members indicated by **14A–N**, which can be of any known type able to work with a refrigerant solution circulating through a GAX device. These valve means could possibly be grouped into a single multi-way device.

With reference to FIG. 2, the operating cycle of the device when in heating mode is such that the refrigerant vapour leaving the branch **7G** of the generator **1** via the valve **14B** and the branch **15I** reaches the inlet of the sub-heat exchanger **10A** which in this operating mode operates as a condenser. The vapour condenses within this condenser and becomes liquid to generate heat which is transferred to the liquid circulating through the heat exchanger and through the hydraulic circuit **11** (FIG. 1A, B) connected to said condenser in order to be used for heating.

It should be noted that during this stage the valve **14C** is also shifted so that the dead branches **15E** and **F** can also be reached by the vapour.

The relatively hot pressurized liquid passes through the outlet branch **15E**, the valve **14F**, the branch **15C** and the condensation valve **16** to reach the recuperator **4** in which, as described hereinafter, transfers heat to the vapour originating from the heat exchanger **9**.

The refrigerant liquid then passes through the outlet branch **15D**, the expansion valve **17**, the valves **14D** and **E** and the inlet branches **15E, F, T, T', 13A, B** and **12A**, to enter either the whole of the heat exchanger **9** or its part **9A** or **9B**. When in this operating mode this heat exchanger operates as an evaporator to convert the entering liquid into vapour and to cool the air circulating over the heat exchanger, i.e. to recuperate heat from the outside.

It should be noted that during this stage the valves **14G, H** are also shifted so that the dead branches **15E'** and **15T** can also be reached by the liquid.

The relatively cold, low pressure vapour from the outlet branches **12A** and **15V** passes through the valves **14A, 14I** and the branches **15O, Q, Q'** to the recuperator **4** where it receives heat from the liquid originating from the condenser **10**, and enters the heat exchanger **2** of GAX type via the outlet branch **15R**.

It should be noted that during this stage the valves **14G** and **14L** are also shifted so that the dead branches **15P** and **15O'** can also be reached by the vapour.

From the GAX heat exchanger **2** the solution passes through the outlet branch **15S**, the valves **14H** and the branch **15E** to enter the part **10B** of the heat exchanger **10**, and also passes through the outlet branch **15M**, the valve **14N** and the further branch **15H, H'** to also enter the other part **10C** of the heat exchanger. When in this operating mode these two heat exchanger parts **10B** and **10C** are in series and operate as an absorber, to transfer heat to the liquid circulating through the said heat exchangers **10B** and **10C**, which is used by the hydraulic circuit **11** for heating.

The absorber could instead comprise a single sub-heat exchanger **10B** or **10C** even though it has been found experimentally that two sub-heat exchangers positioned in series provide improved performance.

It should be noted that during this stage the valve **14M** is also shifted so that the solution can also reach the dead branches **15H, G**.

The solution finally passes through the outlet branch **15N'**, the valve **14L** and the branch **15U** to reach the pump **3**, from which it passes through the branch **15Z** to reach the gen-

erator **1**. It should be noted that during this stage the dead branches **15N', N''** are also reached by the solution.

With reference to FIG. 3, the operating cycle of the device when in cooling mode is such that the refrigerant vapour leaving the generator through the branch **7G** passes through the valve **14B** to the inlet branch **15A** of the sub-heat exchanger **9A** which in this operating mode operates as a condenser. In this condenser the vapour is maintained under pressure and is cooled to become liquid. The vapour transfers heat to the air surrounding the condenser **9A**. The relatively hot pressurized liquid leaves the condenser through the circuit branch **15B**, and by way of the valve **14F**, a valve **16** and the branch **15C** reaches the recuperator **4** in which it transfers heat to the vapour originating from the other heat exchanger **10** (as described in detail hereinafter). From the recuperator **14** the liquid passes through the branch **15D**, the expansion valve **17**, the valves **14D, C** and **N**, and the branches **15E–I**, to reach the three inlets of the three sub-heat exchangers **10A–C** of the second heat exchanger **10** which when in this operating mode all operate as evaporator. The pressure of the liquid leaving the recuperator **4** is lowered by the valve **17** and the liquid evaporates within the evaporator **10** to absorb heat and thus cool the liquid circulating through the evaporator **10** and through the hydraulic circuit **11** (FIGS. 1A, B) associated with the evaporator, so as to produce the desired cooling effect. The refrigerant vapour passes through the three outlets of the evaporator **10**, the branches **15L–N**, the valves **14G, N, L** and the further branches **15O–Q** to reach the recuperator **4** where it is heated and from which it enters the GAX heat exchanger **2** through the branch **15R**. The weak solution leaving the GAX heat exchanger passes through its outlet branch **15S**, the valve **14H** and the branches **15T** to reach the second sub-heat exchanger of the heat exchanger **9** which when in this operating mode operates as an absorber. During the absorption process the heat generated is transferred to the air circulating about the heat exchanger **9B**. The solution leaving the absorber passes through the outlet branch **15V**, the valve **14I** and the further branch **15U** to reach the pump, and from there returns to the generator **1** via a branch **15Z**.

It should be noted that by suitable shifting (represented in FIG. 3) of the valves **14A–N** all the dead branches of the circuit are always in communication with a branch in which the solution in one of its various phases circulates.

FIGS. 1A, B show schematically the connections of the generator **1**, of the GAX heat exchanger **2**, of the recuperator **4**, of the rectifier **20** and of the vessel **21**. These connections have not been described in the foregoing description and are not shown in FIGS. 2 and 3. As they are of conventional type for the expert of the art, they are not described in detail hereinafter.

In FIGS. 1A and 1B the circuit flows which are common both to the heating stage and to the cooling stage are shown by full lines, the circuit flows relative to the heating stage are indicated by dashed and dotted lines (FIG. 1A) and the circuit flows relative to the cooling stage are indicated by dashed lines (FIG. 1B).

When the device of the invention is in heating mode the heat exchanger **9** can be defrosted. For this purpose, operation in heating mode is interrupted and for a predetermined time, for example four minutes, the device is made to operate in cooling mode. In this manner a high temperature solution is circulated through both parts **9A–B** of the heat exchanger **9**, to defrost the heat exchanger without the need to use external heat sources. This operation is also easier and quicker than that of the known art.

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As the device of the invention comprises only two heat exchangers **9** and **10** which, depending on the operating mode, perform the three functions of evaporator, condenser and absorber, it is more compact and reliable. This arrangement also enables a single hydraulic circuit to be provided (FIGS. 1A, B) associated with the heat exchanger **10**, for heating or cooling the liquid necessary to obtain the required operability of the device. In this manner the device is easier to handle and control and has a smaller number of components than the devices of the known art.

It should also be emphasized that the device of the invention comprises a hydraulic circuit with its valve members **14A–N** controlled in such a manner that in no stage of its operation does it leave dead branches, i.e. branches not reached by the solution. Consequently, the circuit of the device requires a smaller number of overpressure members and in general of control means, which are simpler and of easier handling.

Finally, it should be noted that the aforescribed embodiment is provided by way of example only, and that numerous variants are possible, all entering within the same inventive concept; thus for example the valve means **8** could consist of a plurality of different valve members instead of consisting of a single sixteen/fourteen-way valve.

The invention claimed is:

**1.** A cooling or heating device in an absorption heat pump of GAX type, comprising:

- a generator;
- a heat exchanger of GAX type;
- an absorber;
- a condenser;
- an evaporator;
- a pump connected to said absorber and generator;
- a first circuit for refrigerant solution circulating through the device and connecting together at least said generator, GAX heat exchanger, absorber, condenser, evaporator, and pump; and
- a valve device configured to modify said first circuit to vary a manner in which the absorber, condenser, and evaporator are connected together;
- at least a first and a second heat exchange means for enabling at least one phase of the refrigerant solution circulating through said first circuit to be changed and to enable thermal energy to be exchanged against an external fluid, said first and second heat exchange means each comprising at least first and second mutually separate sub-heat exchangers arranged to function either as an evaporator or as an absorber and condenser, depending on an operating mode of the device.

**2.** A device as claimed in claim **1**, wherein when the device operates in a cooling mode, the valve device is configured to modify the first circuit such that the first heat exchange means operates as an evaporator, said first sub-heat exchanger of the second heat exchange means operates as a condenser and said second sub-heat exchanger of the second heat exchange means operates as an absorber, whereas when the device operates in a heating mode said valve device is configured to modify said first circuit such that said first sub-heat exchanger of the first heat exchange means operates as a condenser and said second sub-heat exchanger of the first heat exchange means operates as an absorber, and the second heat exchange means operates as an evaporator.

**3.** A device as claimed in claim **1**, wherein the first and second heat exchange means comprise at least the first and second separate sub-heat exchangers that are only two in number.

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**4.** A device as claimed in claim **1**, further comprising a single hydraulic circuit for circulation of a liquid and configured to withdraw or receive thermal energy generated by the evaporator or by the condenser or by the absorber.

**5.** A device as claimed **1**, wherein the first circuit through which the refrigerant solution circulates and the valve device are formed to avoid dead branches not reached by said refrigerant solution, in two operating modes of the device.

**6.** A device as claimed in claim **1**, wherein in the second heat exchange means heat exchange takes place between the refrigerant solution and air circulating on an outside of said heat exchanger.

**7.** A device as claimed in claim **1**, wherein in the second heat exchange means heat exchange takes place between the refrigerant solution and a circulating liquid both of which lie within said second heat exchange means.

**8.** A device as claimed in claim **7**, wherein the second heat exchange means comprises a substantially tube-shaped casing having an inlet and an outlet for a first fluid, and a plurality of tubes disposed longitudinally in an interior of said casing; each tube being connected to an entry element and an exit element for a second fluid, the first fluid circulating within an interior of the casing in contact with outer solutions of said tubes; the tubes inside the casing being substantially directly in contact with each other and with the inner walls of said casing and having a cross-section to form within the casing a plurality of micro-channels parallel to the tubes for circulation of the first fluid.

**9.** A device as claimed in claim **8**, wherein between entry and exit portions the tubes present at least one portion having a cross-section of shape different from that of adjacent tube portions, the shape being such as to at least partly break and remix the flow of fluid circulating through the tube, and portions of the tube having a cross-section of different shape being formed of telescope shape and/or being in contact with each other, to maintain the tubes spaced apart.

**10.** A device as claimed in claim **8**, wherein the heat exchanger is of S shape, the casing housing the tubes comprising two semi-circular shells in correspondence with a curved portion.

**11.** A device as claimed in claim **7**, wherein the second heat exchange means comprises three separate side-by-side sub-heat exchangers.

**12.** A device as claimed in claim **1**, wherein the valve device includes a single valve comprising a plurality of valve members.

**13.** A device as claimed in claim **12**, wherein the single valve is a sixteen/fourteen-way valve.

**14.** A method for controlling solution and/or refrigerant in a device claimed claim **1**, using the at least first and second separate sub-heat exchangers of the at least first and second heat exchange means either as an evaporator or as an absorber and condenser, according to the operating mode of the device.

**15.** A method for controlling solution and/or refrigerant in a device claimed in claim **1**, avoiding dead branches not reached by said solution and/or refrigerant, in two modes of operation of the device.